

Outline

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- Commercialization Strategy – Fuel Cell Vehicles
- Technology “Road Map”
- Key Technology Objectives
- Technology Advancement Proof Points
 - Catalyst development
 - Understanding membrane failure
 - Continuous Processing for cost reduction
- Demonstration fleets and field trials
- Summary

Required Elements for Commercialization

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FCV Commercialization

Economic Incentive

Performance

Reliability

Cost

Field Validation/Service

Freeze Start

Durability

Power Density

Cost

Technology Demonstration

Fuel Cell

Balance of Plant

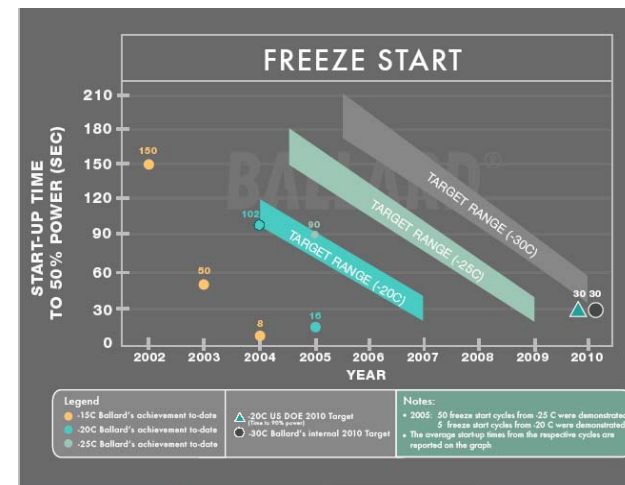
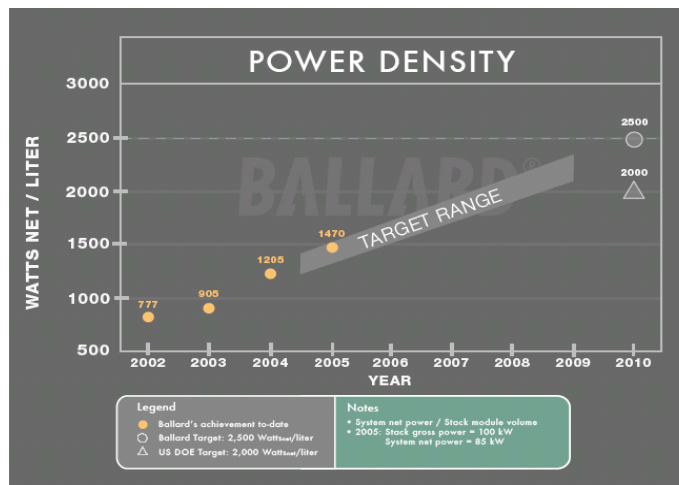
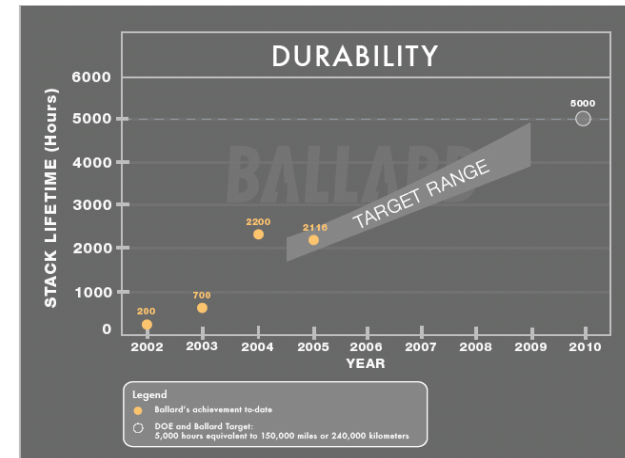
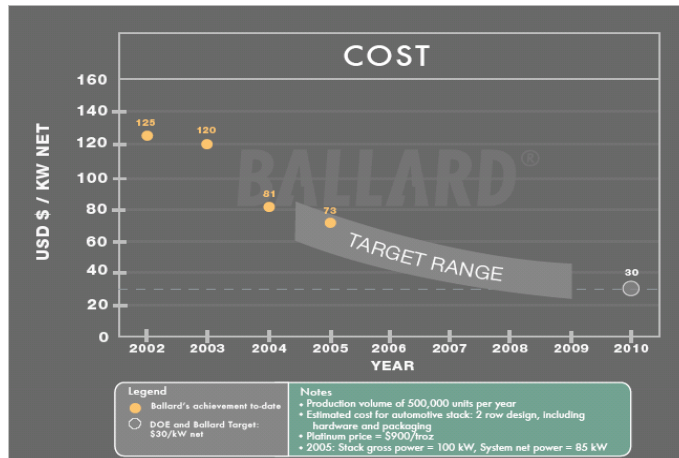
Electric Drive

Fundamental Understanding

Technology "Road Map" Summary

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Technology Imperatives

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- Execute Technology “Road Map” to demonstrate a commercially-viable fuel cell technology by 2010
- Enhance strategic relationships with key unit cell component suppliers
 - Supply based needs to be encouraged to keep spending R&D dollars and to break the price/volume paradigm
- Accelerate emerging technologies; e.g.
 - Hydrocarbon composite membranes
 - Catalyst-loading reduction – with enhanced voltage efficiencies
 - Metal plate technologies

Key Technology Development Objectives

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- Effective water management is essential to achieve performance and durability targets
 - Develop materials and design solutions, coupled with operational strategies that drive improved system efficiencies
- Accelerate design selection through improved “tools” and related modeling & simulation expertise
 - accelerated tests to define durability issues
- Engineered electrocatalyst layers
 - Catalyst loading reduction with improved performance; mitigation of known failure mechanisms

Key Technology Development Objectives

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- Low-cost composite membranes
 - Increased ionic conductivity and x-y plane dimensional stability
 - Introduce hydrocarbon ionomers
- Low-cost, continuous GDL deployment
 - Facilitate continuous manufacturing process development for volume and cost reduction

2005 Technology Demonstration

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Achieved further improvements in three key fuel cell stack performance metrics – in a single stack design...

Freeze Start

- Performed 50 consecutive freeze starts from -25° C (90 sec)

Durability

- Demonstrated stack lifetime of more than 2,000 hours

Cost Reduction

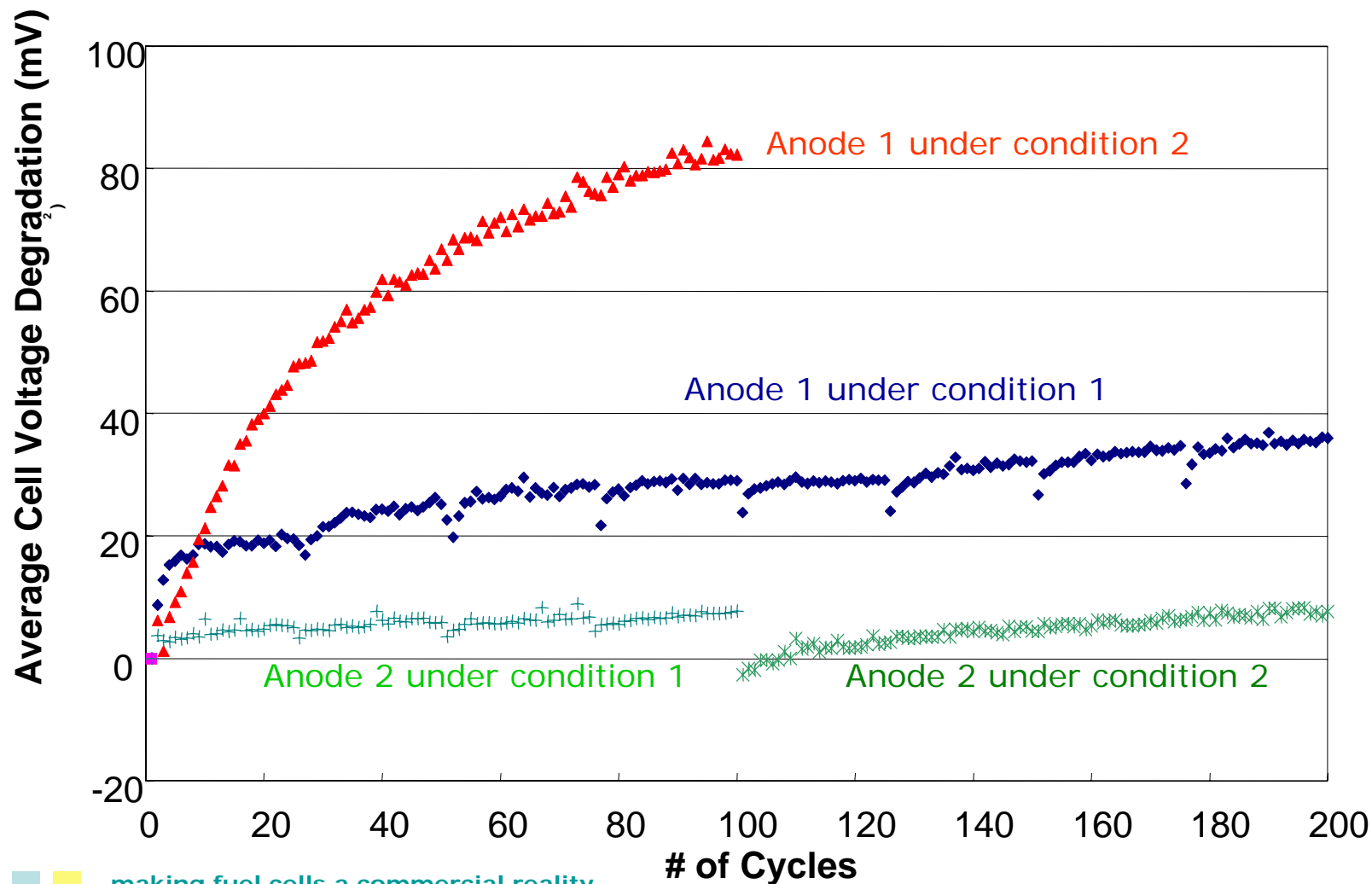
- Reduce cost by 10% over 2004 technology

...while increasing stack power density and operational flexibility by running the durability test at reduced inlet Relative Humidity

Improved Anode Catalyst

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Catalyst Technology Advancements

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Platinum

1994

2004

Already Lab
Demonstrated

>2010

8-10 mg/cm²

1.0 mg/cm²

0.3-0.5 mg/cm²

< 0.3 mg/cm²

Processes

hand
coating

screen printing
spraying

roll coating
(knife, comma
bar)

CVD
nanoparticle
dispersion

Catalyst Structure

No catalyst
support

Carbon
Support

Carbon
Support

Corrosion-free
Support

Pt Metal

Pt and Pt alloys

Pt and Pt alloys

Non-PGM or low
Pt content alloys

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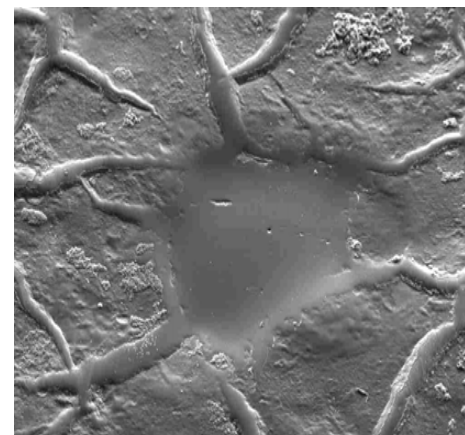
Membrane Degradation

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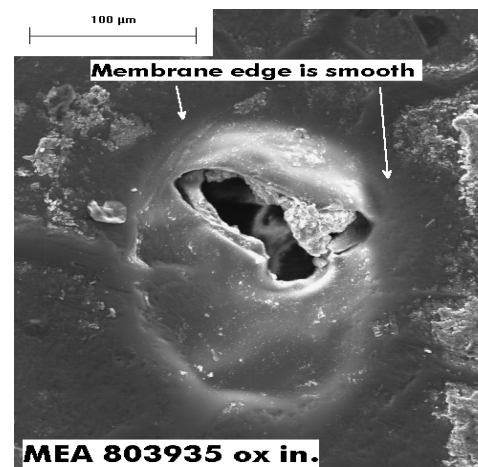
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- Understanding failures:

- Accelerated tests development and mechanistic understanding
- Mitigation and design improvements



Membrane is thinning in discrete areas

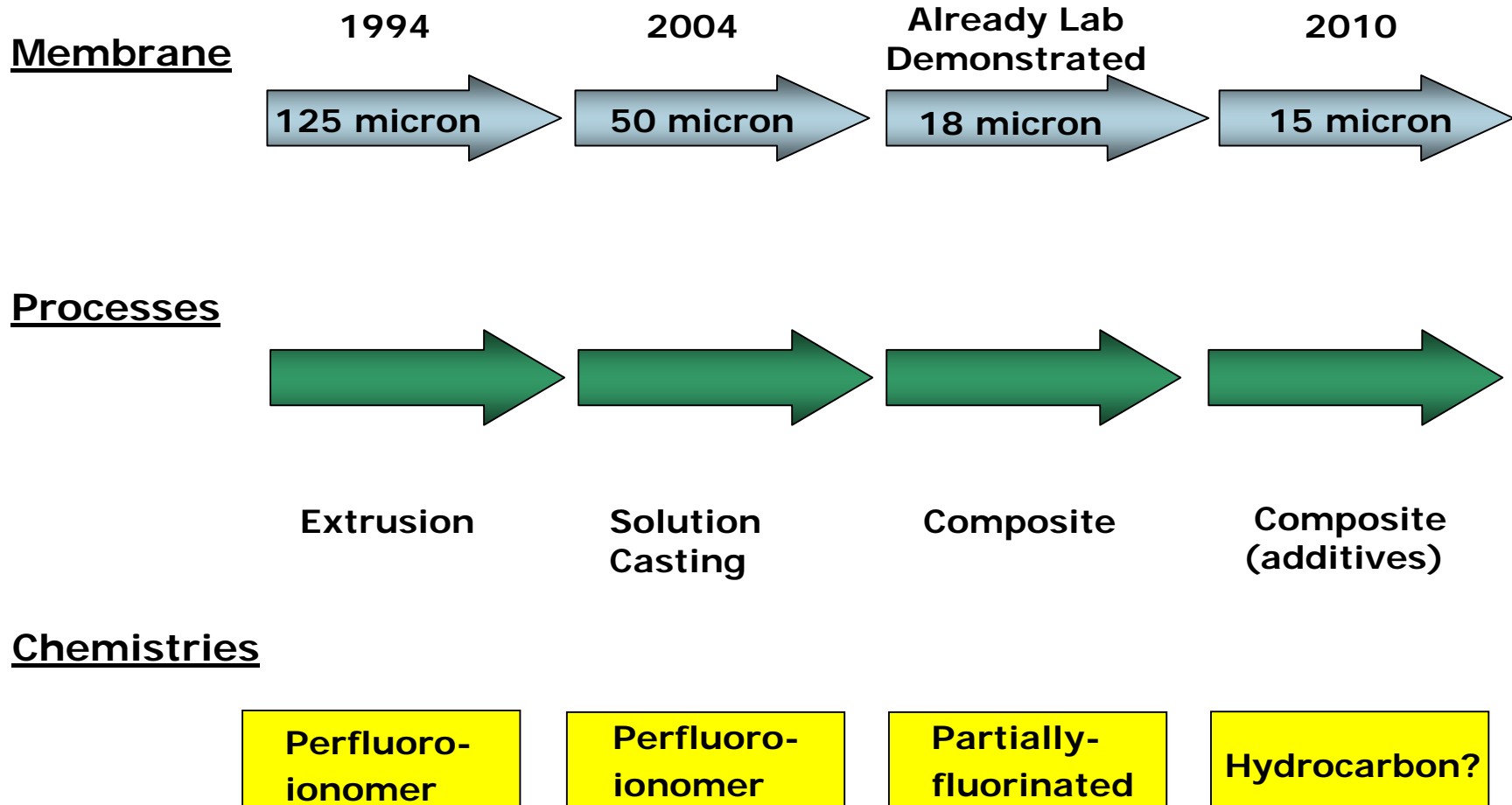


Reduced physical strength – leads to rupture

Membrane Technology Advancements

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Cost Reduction - GDE Continuous Processing

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Finished substrate



Hydrophobic treatment



**GDL Catalyst
Coatings (GDE)**

Durability as a Function of Operating Conditions

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180 kW



**Mark 902
Heavy Duty
Transportation**

- Pressure: 3 bara
- Duty cycle: Medium Dynamic
- Durability: ~3,000 hr

85 kW



**Mark 902
Light Duty
Transportation**

- Pressure: 3 bara
- Duty cycle: Fast Dynamic
- Durability: ~1,000 hr

4 - 21 kW



**Mark9 SSL™
Forklifts**

- Pressure: 2 bara
- Duty cycle: Slow Dynamic
- Durability*: ~10,000 hr

* Based on limited product test data

One design ...

- same stack technology meets needs of many applications
- durability is dependent on operating conditions

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How can California Help?

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- Regulation is critical to drive growth in demonstration fleets – CARB ZEV mandate
- Early adopters of fuel cell products – state owned/run organizations
- State subsidy for “green” vehicles, during ramp to commercial volumes
- Stimulate growth and investment incentives for key component developers/suppliers
- BENEFITS: reduced urban pollution, reduced GHGs, energy reliability and diversity, contribution to sustainable energy future...

Driving Consumer Acceptance

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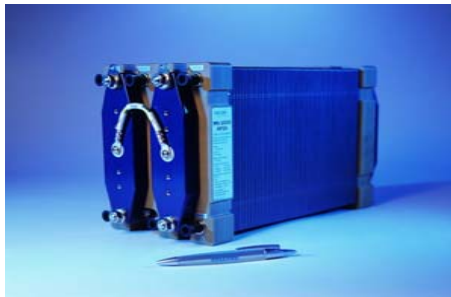
- 130+ vehicles
- 24 cities
- 4.5 million plus passengers
- Real world data

Vehicles powered by Ballard fuel cells have logged more than 2.6 million kilometers

Commercialization Strategy

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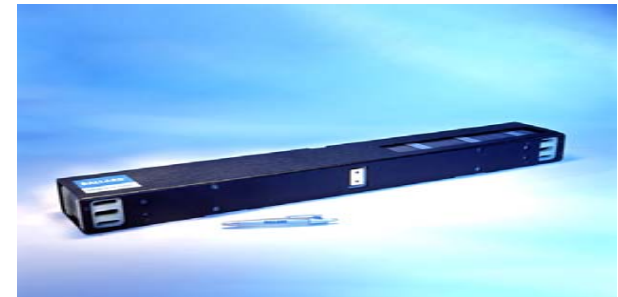
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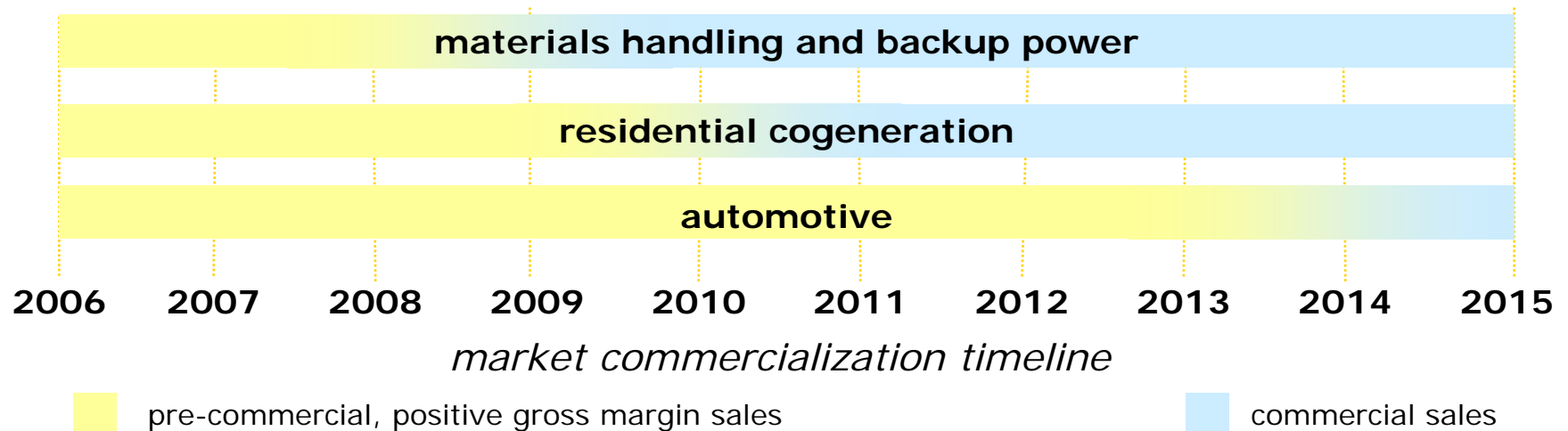
**Residential
Cogeneration:
Mark 1030**



**Automotive:
Mark 902**



**Materials Handling & Backup
Power: Mark9 SSL™**



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